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The Mechanical Properties of Metal-Void Composites

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Work under this Phase I contract is intended to conduct a theoretical feasibility study of the *strength*, *toughness* and vibrational *damping* properties of composite materials consisting of a metallic matrix with a high volume fraction (to 30%) of small (0.1 - 10μm) pressurized voids.

The premise of the approach is that a theoretical study, using both analytical and computer methods, offers a cost-effective means of assessing the probable properties of such composites and their projected utility in aerospace structures.

This interim report summarizes progress of the work in each of the key areas cited above, in turn.

1. Strength

The resistance to dislocation motion of linear void arrays for three void sizes and for void volume fractions up to 30% has been calculated using a full self-stress model for the dislocation and a normal-intersection condition for the dislocation-void image interaction. The results, to be detailed in the final report, confirm that the strength of a void-metal composite is high, of order 80% of the strength of idealised impenetrable dispersoids. This strength should be maintained at high temperature, because the voids are thermodynamically stable, not subject to Ostwald ripening.

Unfortunately, there is a drawback. Since the bypass of a void by a dislocation does not leave an Orowan loop, but simply an internal surface step, the process causes no work hardening, an attribute which can be catastrophic in a service material. Therefore, although the dislocation-void interaction specifics meet the conditions necessary to usefulness of the proposed material, they are by no means sufficient.

It is predicted that the grain boundary-void interaction will provide sufficiency. Voids will provide strong anchors for grain boundaries, and will serve both to inhibit grain boundary motion and to restrict the grain size to

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that of the initial powder. The resulting rigid substructure will trap dislocations and afford the necessary measure of work hardening.

2. Toughness

Finite element methods (FEM) have been used to calculate the stress and elastic energy distributions due to two-dimensional void arrays. These calculations are relevant to the question of toughness because crack propagation will occur preferentially through regions of high elastic energy density and will be inhibited if voids are intersected or if the energy density is low. To date, computations have been performed for materials with void volume fractions of 30%, subjected to uniaxial tensile stresses and to internal void pressures. The results indicate that the load is transmitted through void-free, matrix channels, in which the stress is enhanced. In the intervening channels, which contain the voids, the stress levels are reduced because of the elastic shielding effect of the voids.

It is predicted that while crack propagation will proceed readily across the matrix channels, arrest will occur at the intervening channels when the crack either blunts at a void or slows in a region of depleted elastic energy density. The expectation, therefore, is that void composite materials will exhibit toughness equal to or greater than that of the void-free matrix.

3. Damping

Qualitative consideration of scattering physics indicates that vibrational damping can be divided into three classes. Short waves, with wavelength less than the mean spacing of the voids, will be scarcely affected. Very long waves will be similarly unaffected. There will be an intermediate region in which medium wavelength vibrations will be scattered strongly into short wave form.

Dynamic FEM calculations will be performed to determine the wavelength limits of the three classes. It is anticipated that the range of damped vibrations will fall short of that required for SDI space structures. However, it is possible that the large wavelength limit might be extended by the use of hierarchical structures; in anticipation of a Phase II proposal, some attention will be paid to this possibility.

Statement A per telecon Dr. Steve Fishman
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